

Abundance Measurements in the intracluster medium

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Outline

O and Mg in the ICM up to $0.2-0.3r_{180}$ with
Suzaku

Radial profiles of Fe abundance up to $0.3-0.5r_{180}$
with XMM and iron-mass-to right ratio

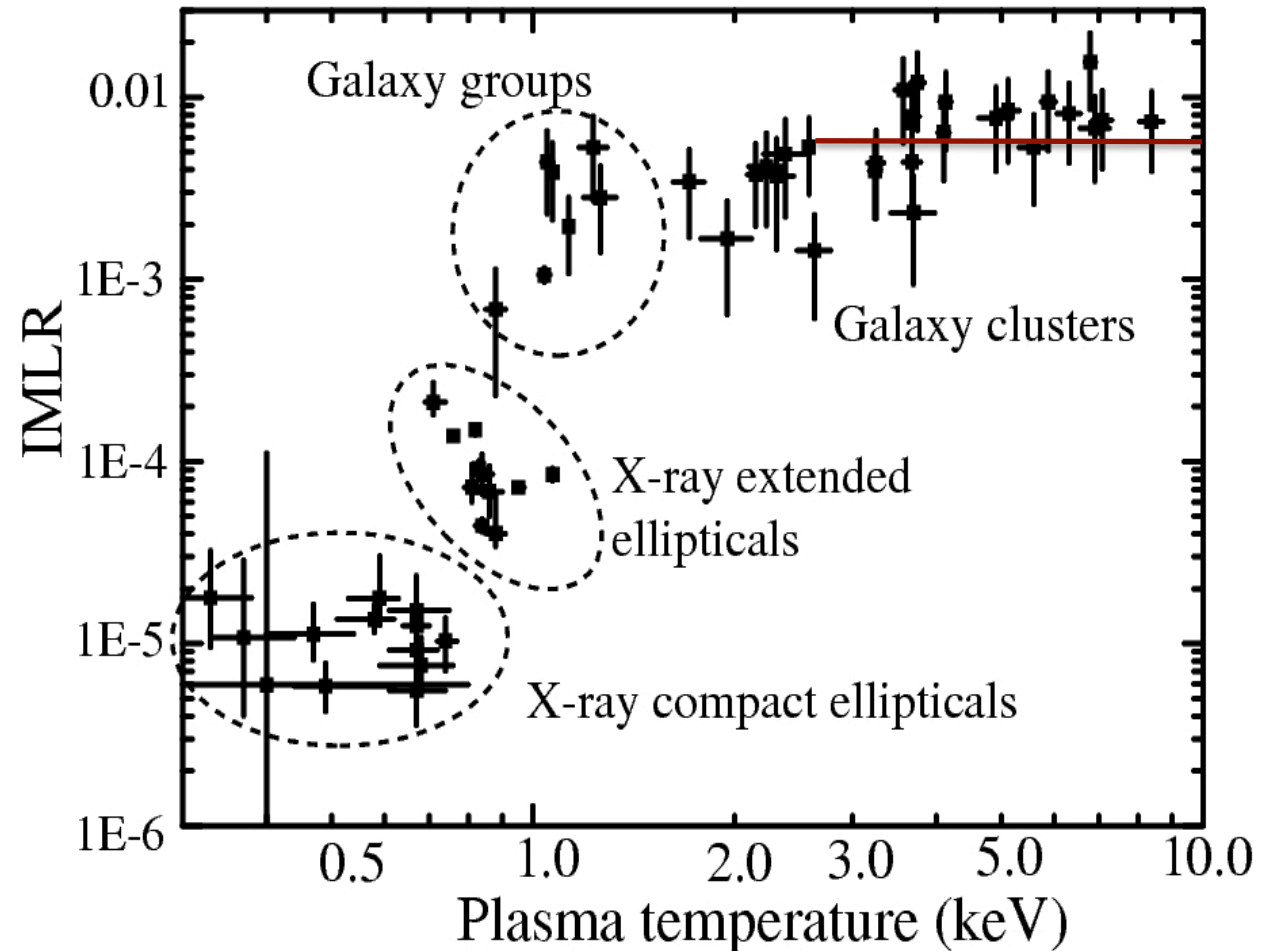
Rare metals with Astro-H

Metals in the ICM

Iron mass in the ICM
stellar luminosity

Iron mass in the ICM is comparable to that in stars in cluster galaxies

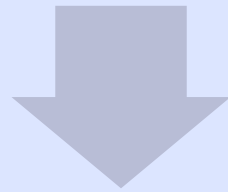
Clusters of galaxies contain all the metals synthesized in cluster galaxies?



ASCA Makishima et al. (2001)

Goals of observing metals in the ICM

Metal mass in the ICM?



initial mass function of stars and
star formation history in clusters

Metals in the Intracluster medium

O,
Mg

- From SN II
- Formation history of high mass stars in clusters

Si, S,
Fe, Ni

- From SN Ia and SN II
- History of SN Ia and SN II

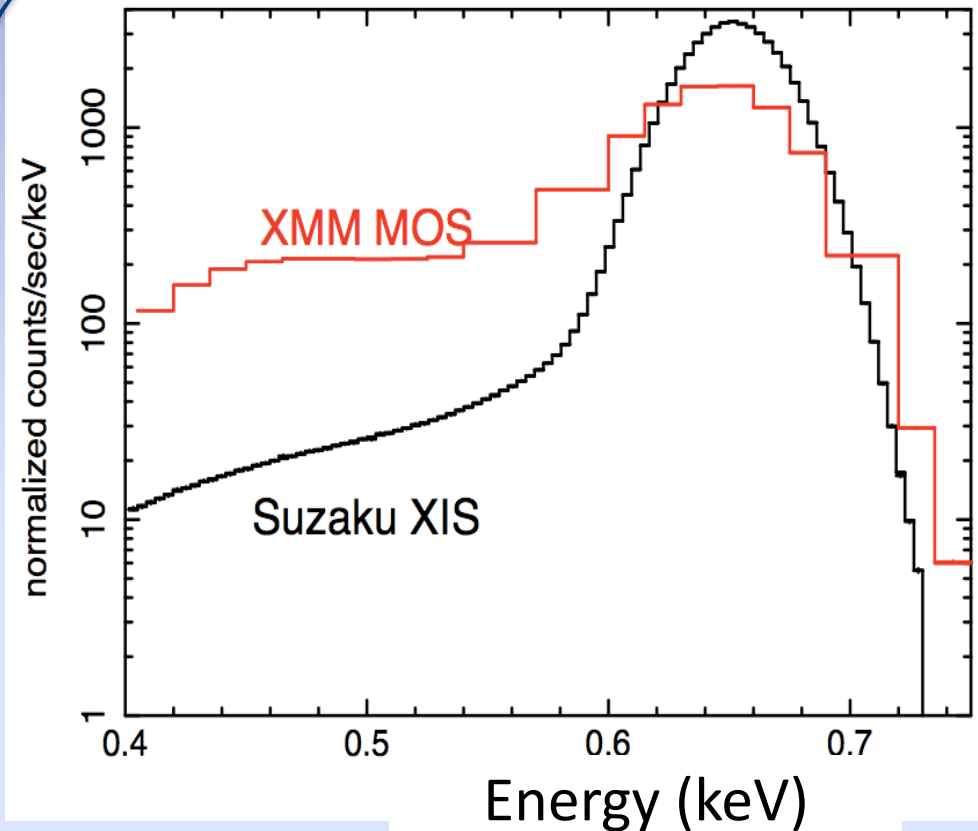
Star formation
and chemical
evolution history
in clusters

Suzaku provides
better sensitivity
to O and Mg lines

Advantages of Suzaku satellite

The XIS instrument onboard Suzaku (2005-) has

- an better line spread function due to a very small low-pulse-height tail below 1 keV
- energy range around O lines is not suffered by strong Fe-L lines
- a very low background.

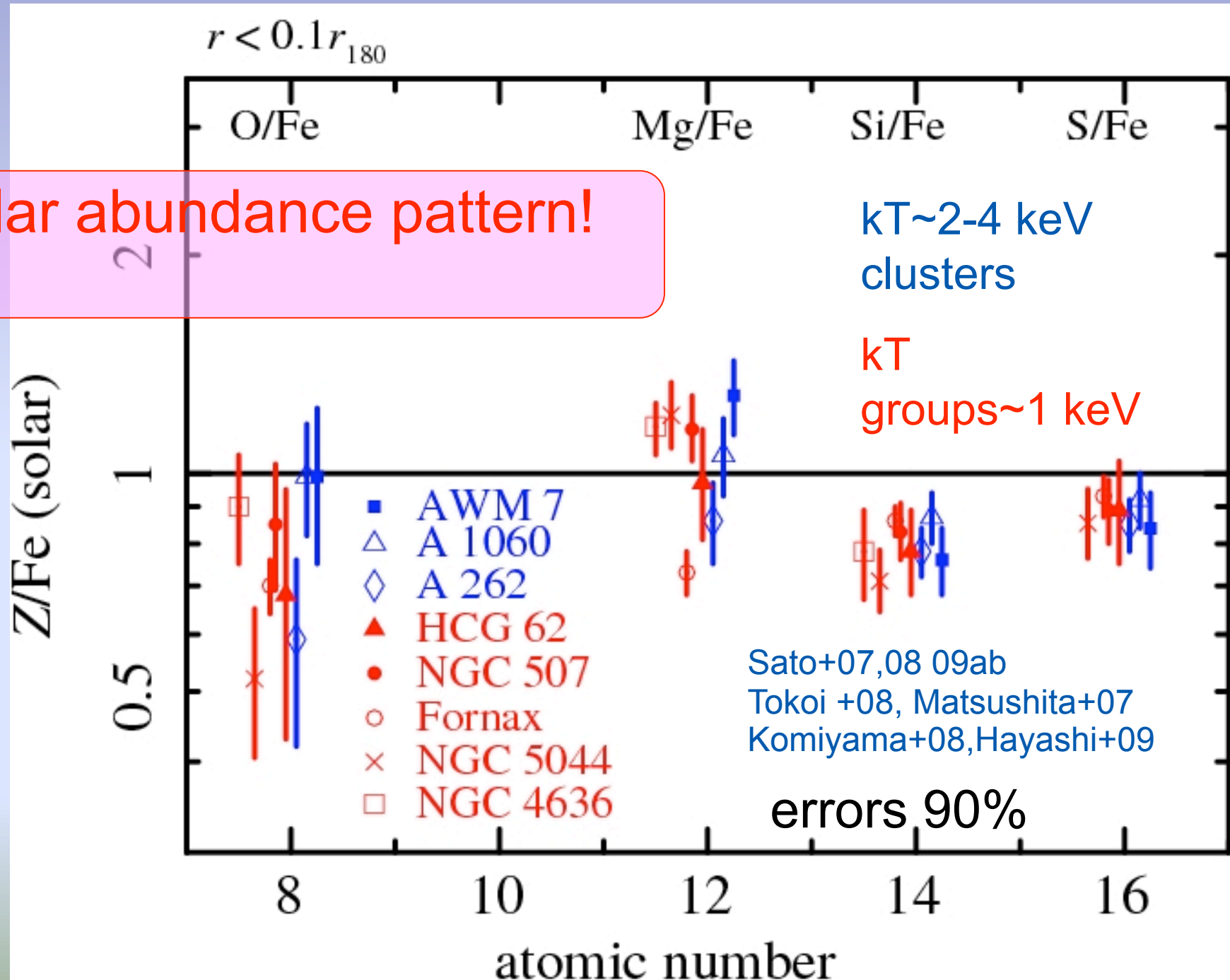


Response of a line at 0.65 keV of XMM-MOS and Suzaku XIS detectors

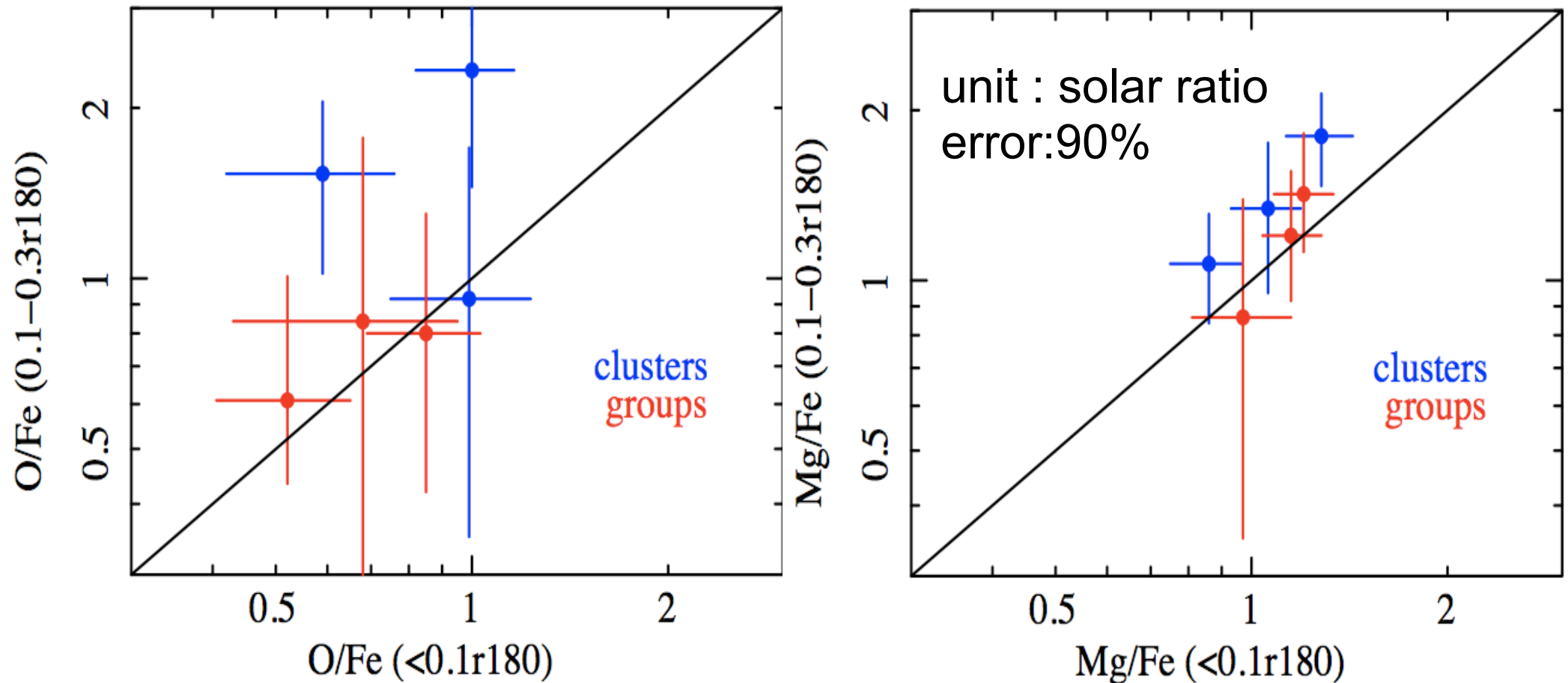
O and Mg in ICM within $0.1r_{180}$ observed with Suzaku

solar abundance table by Lodders (2003)

Solar abundance pattern!



Increase of O/Fe, Mg/Fe ratio at $0.1-0.3r_{180}$



In clusters of galaxies, metals synthesized by SN II tend to be more extended than SN Ia products

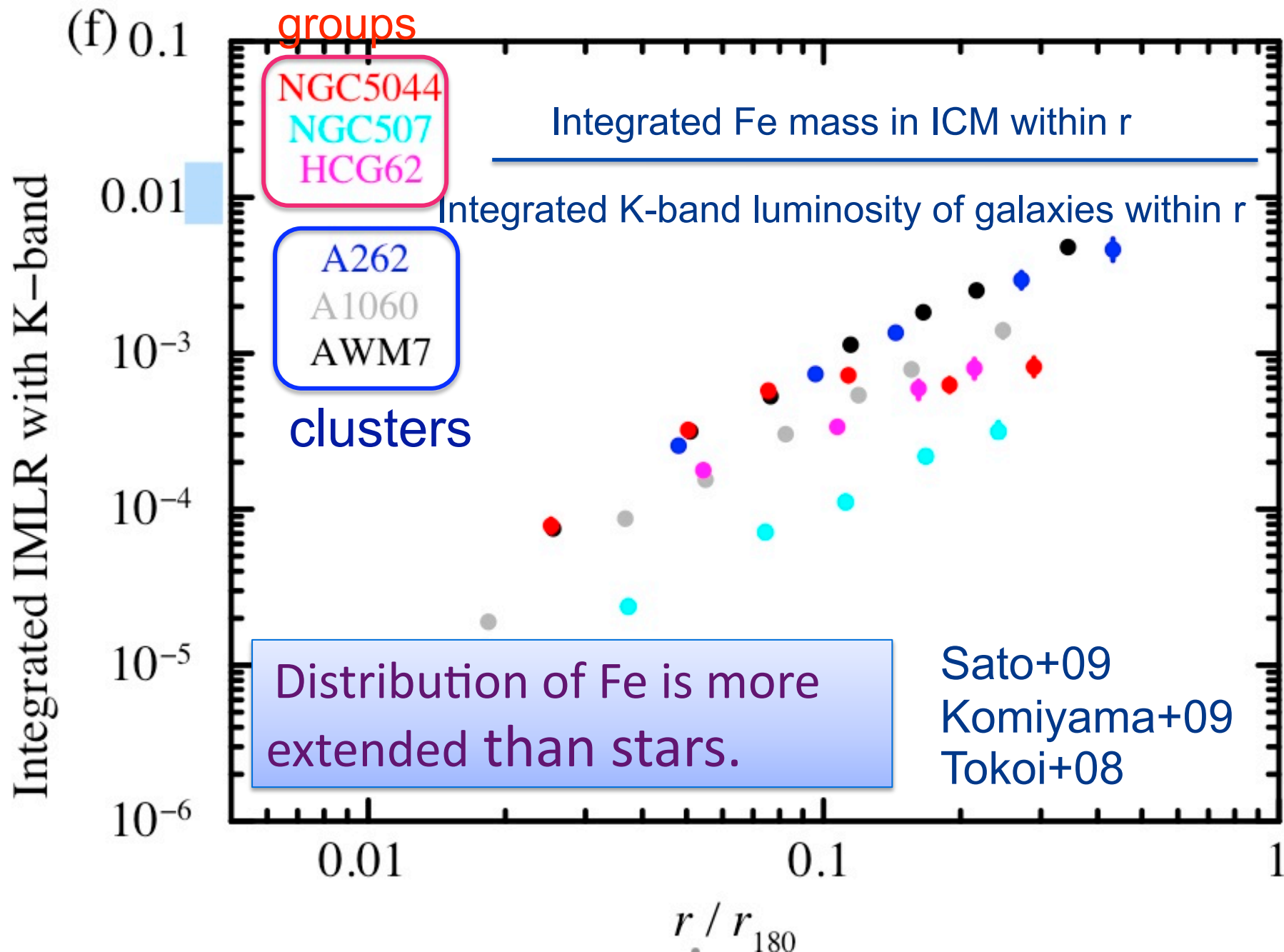
Origin of metals in ICM

Abundance pattern of ICM within $0.1r_{180}$ is close to the new solar abundance by Loddars (2003)

- 70-80 % of Fe are synthesized by SN Ia (Sato+07)

The O/Fe and Mg/Fe ratios tend to be higher in $0.1-0.3r_{180}$

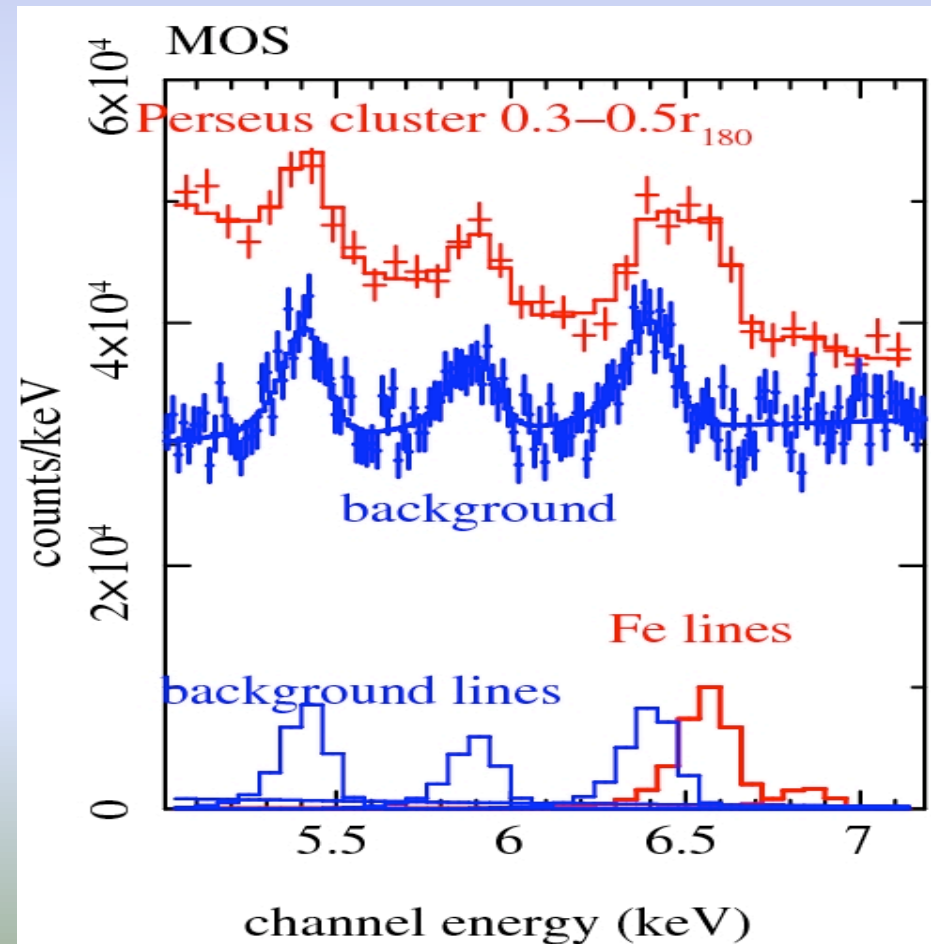
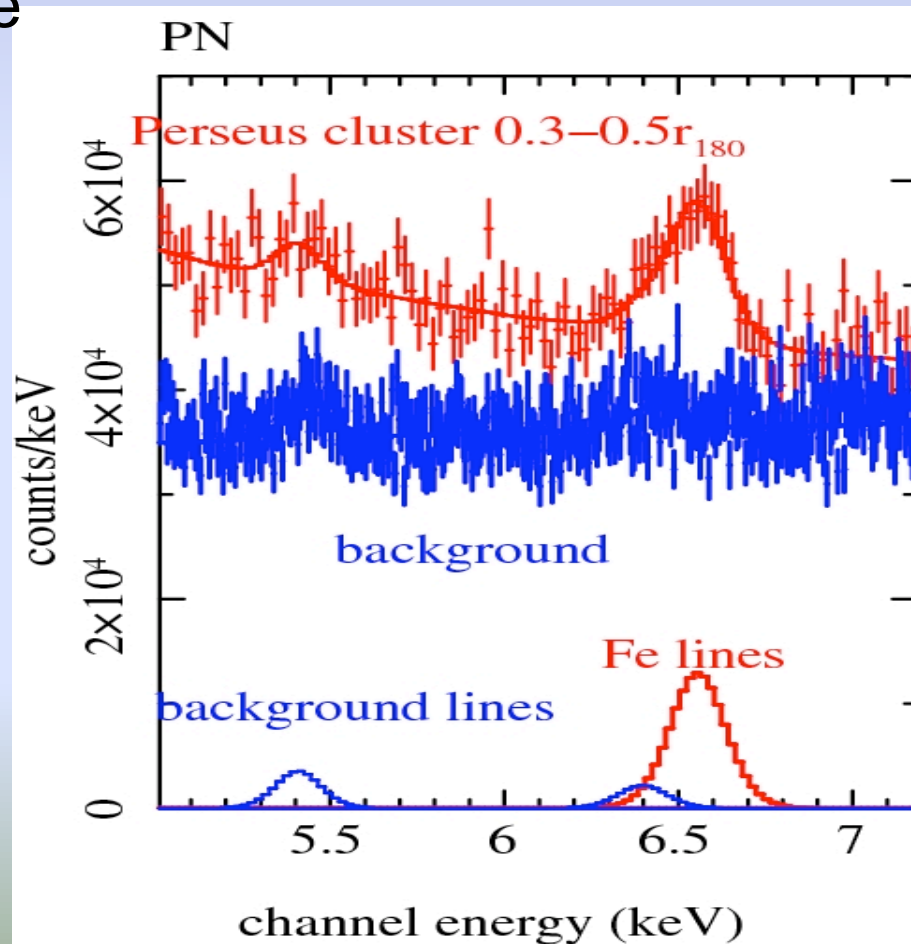
Integrated Fe mass to light ratios



Fe abundance of the ICM in 28 nearby clusters with XMM $z < 0.08$

Matsushita submitted to A&A

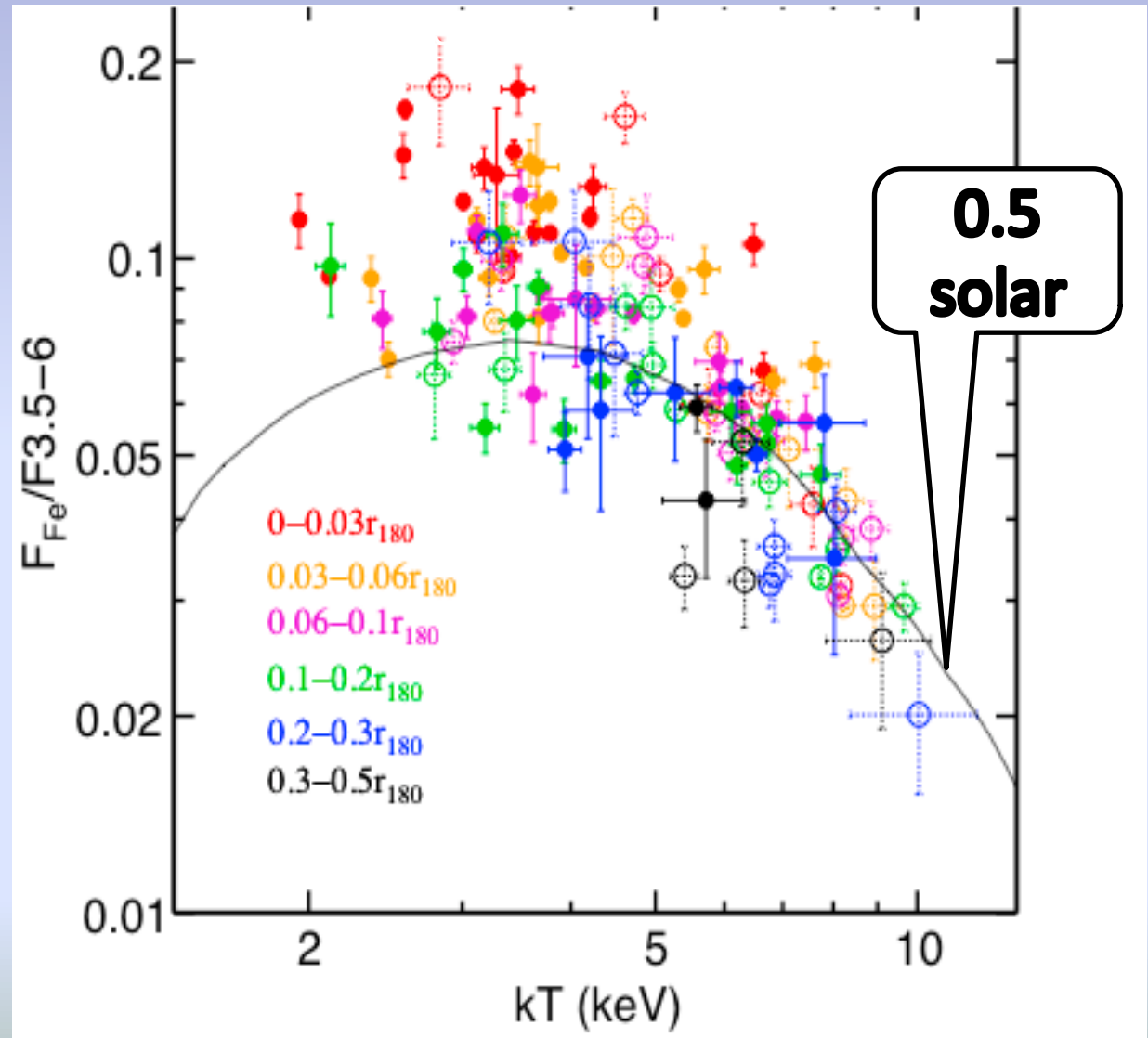
We derived Fe abundances from the flux ratios of Fe lines to the continuum within an energy range of 3.5–6 keV to minimize and evaluate systematic uncertainties due to background and temperature structure



Flux ratio of the He-like Fe line and continuum(3.5-6keV)

Dependence of the ratio on the plasma temperature is rather weak within 20% of 2-6 keV.

Below 6 keV, the uncertainty in the Fe abundance due to temperature structure is small

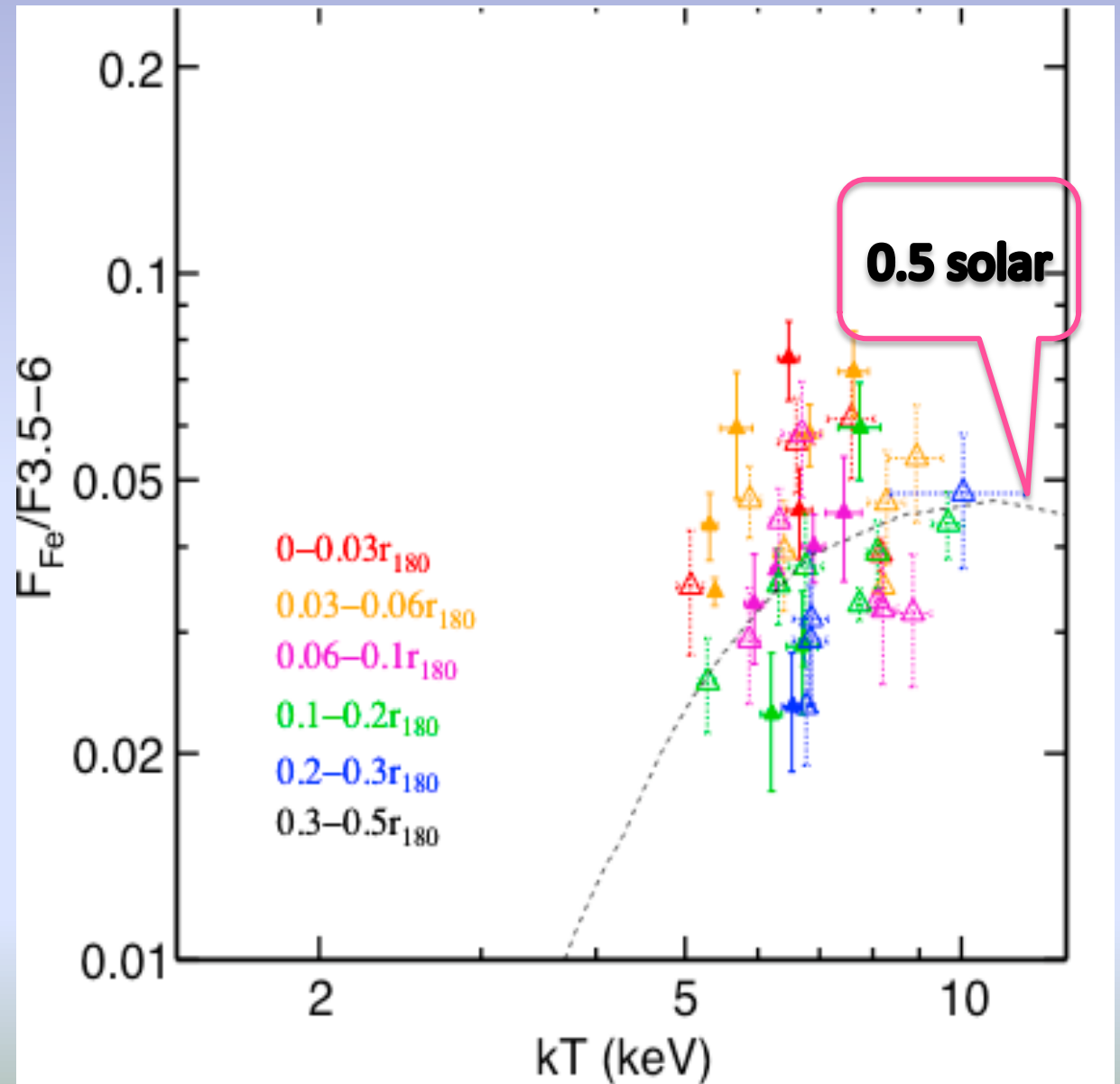


Flux ratio of the H-like Fe line and continuum(3.5-6keV)

Weak temperature dependence within 20% of 7-17 keV



The systematic uncertainty in the Fe abundance is smaller above 6 keV



Radial dependence of the Fe abundances

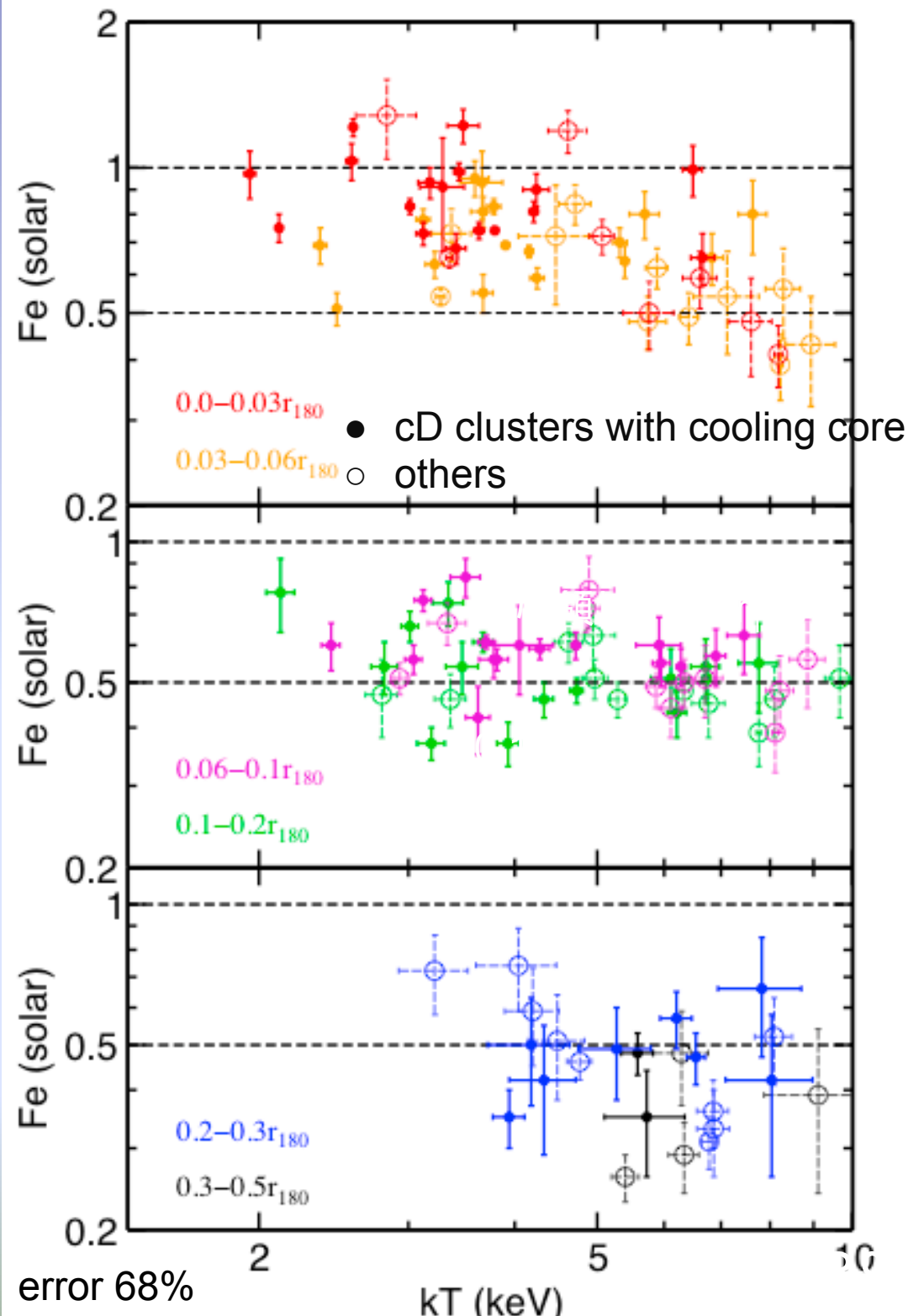
Fe abundances are derived from the flux ratios of He-like Fe line and the continuum

$<0.06r_{180}$

- Scatter
- Difference in recent metal enrichment from the cD galaxies

$0.1-0.3r_{180}$

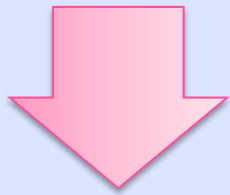
- Small scatter



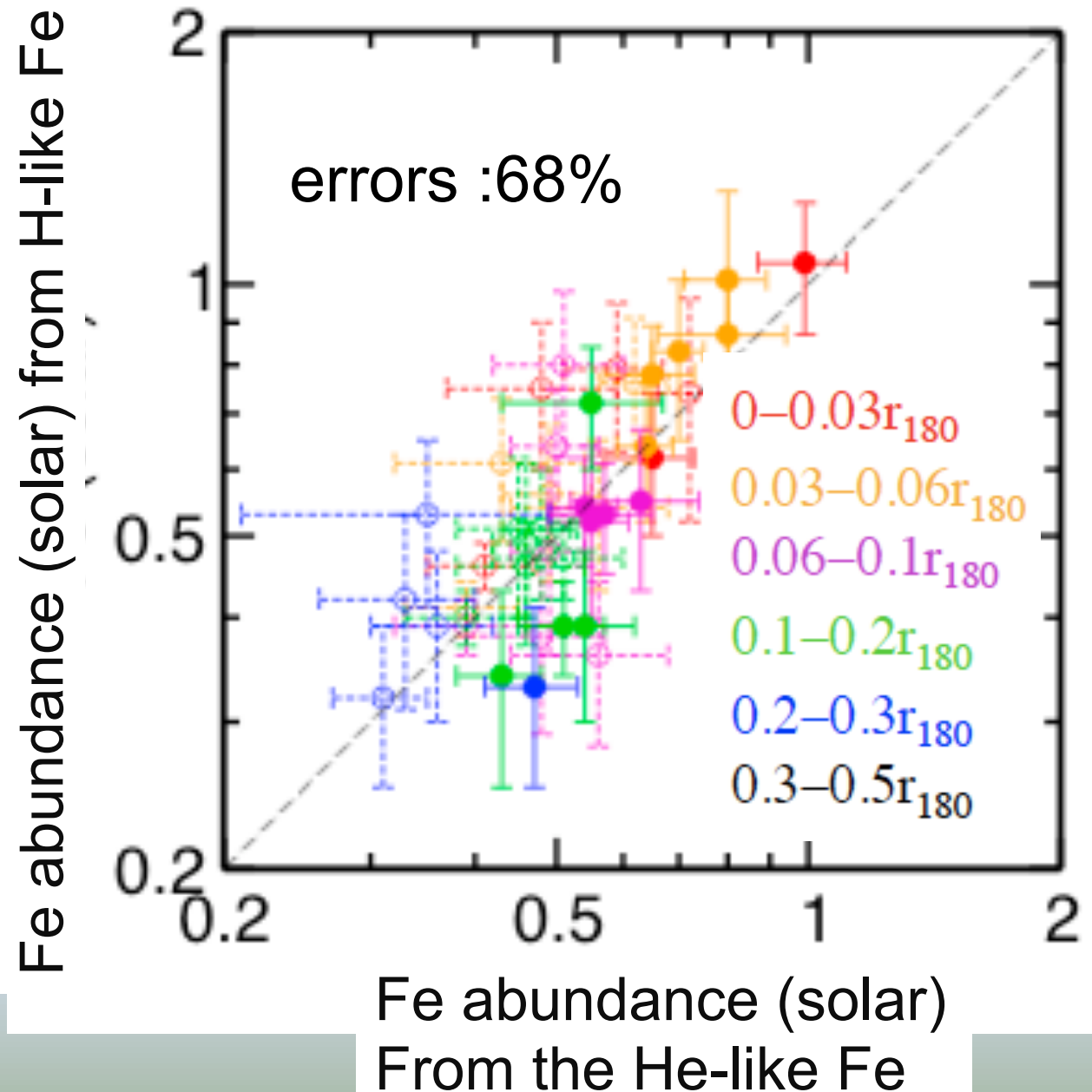
Systematic uncertainty in the Fe abundance

He-like vs. H-like

He-like and H-like
Fe lines give
consistent Fe
abundances



Small systematic
uncertainty



systematic uncertainty in the Fe abundance: multi kT vs. single kT

Fe abundance derived from
the flux ratio of the Fe lines
and the continuum using
best-fit multi-temperature
model

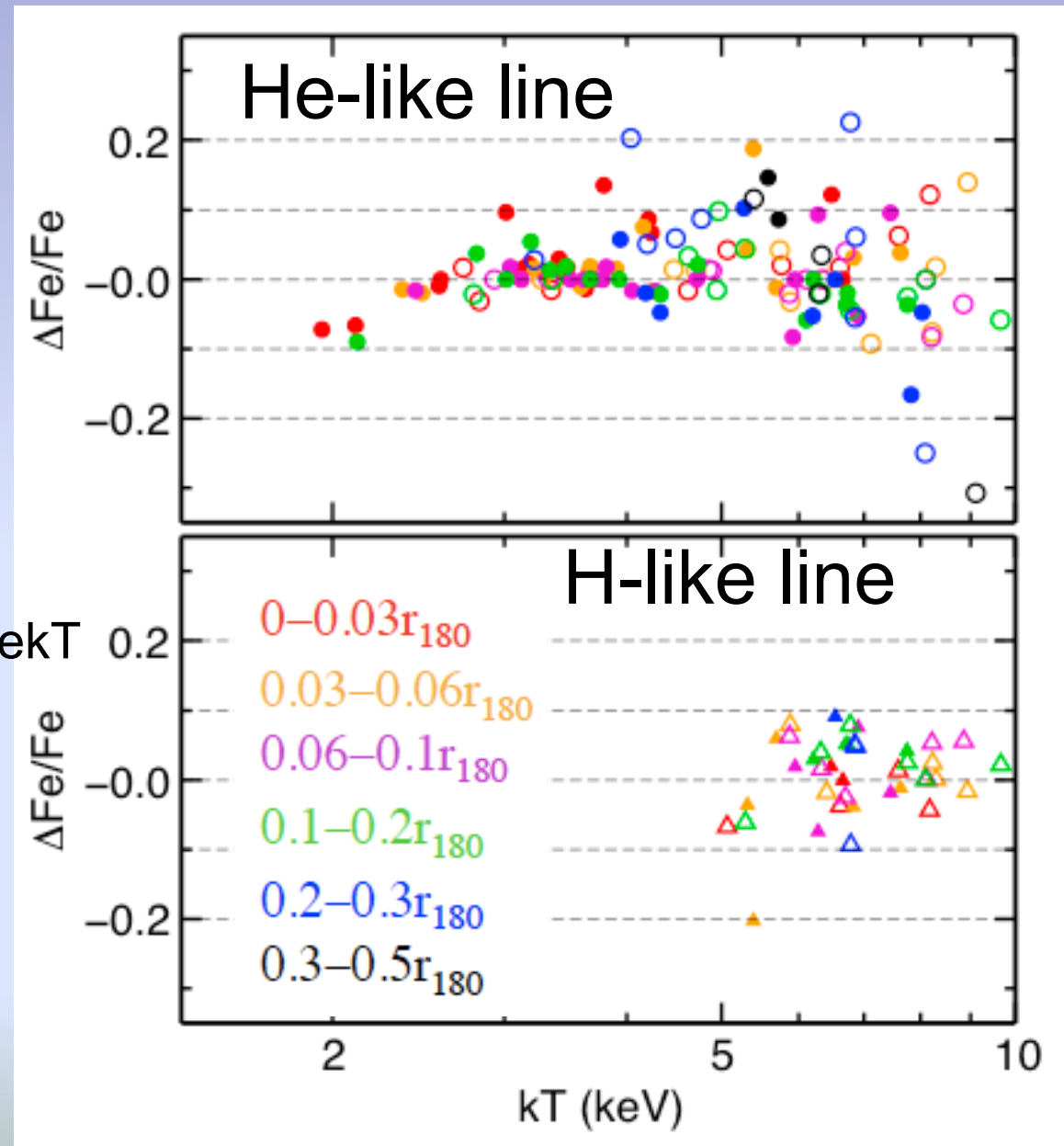
$\Delta\text{Fe} =$

$$(\text{Fe}_{\text{multi kT}} - \text{Fe}_{\text{single kT}}) / \text{Fe}_{\text{single kT}} \leq 10-20\%$$

He-like < 5keV

H-like > 5keV

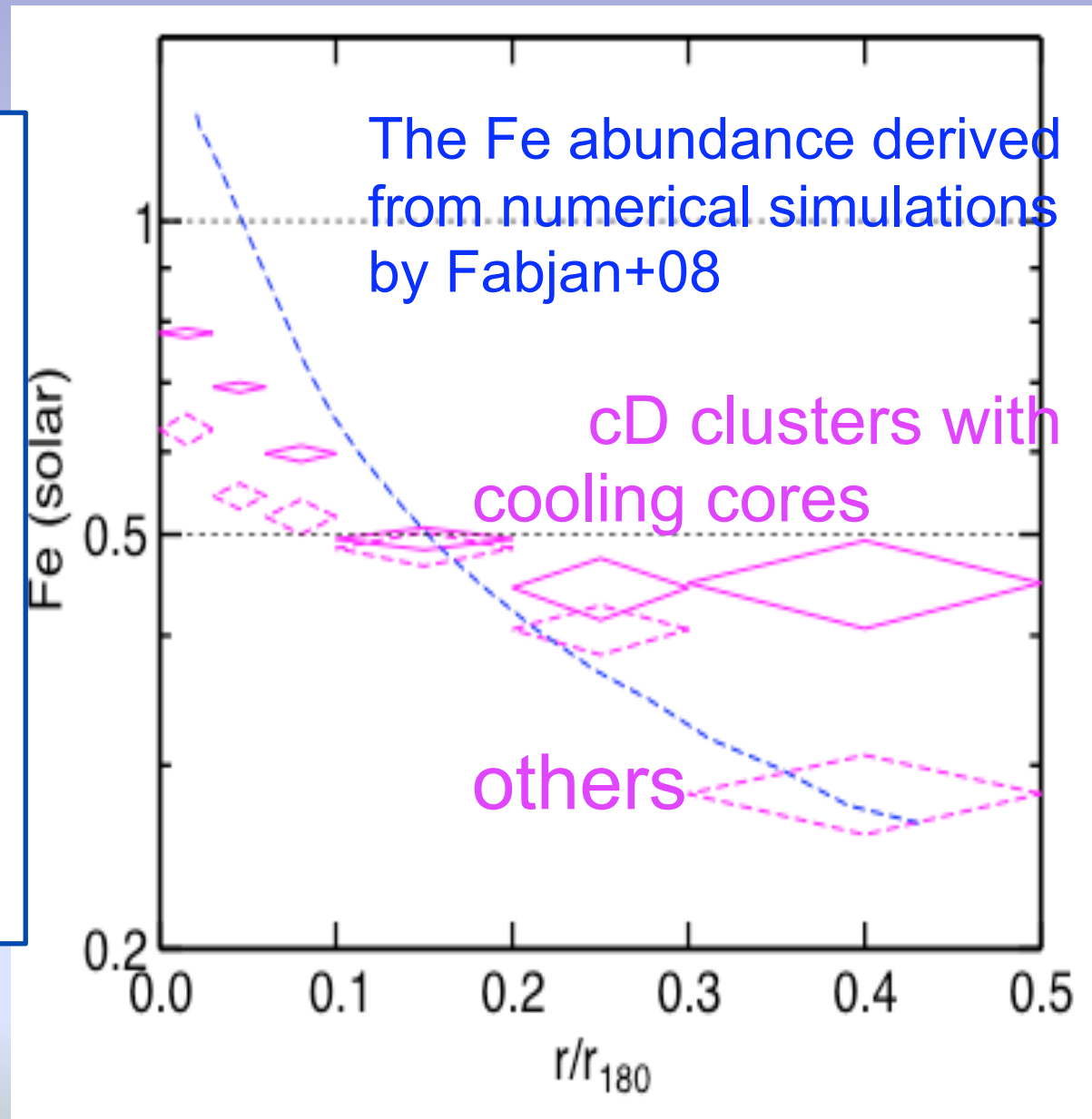
systematic uncertainty
due to temperature
structure is small



The average Fe abundance profiles

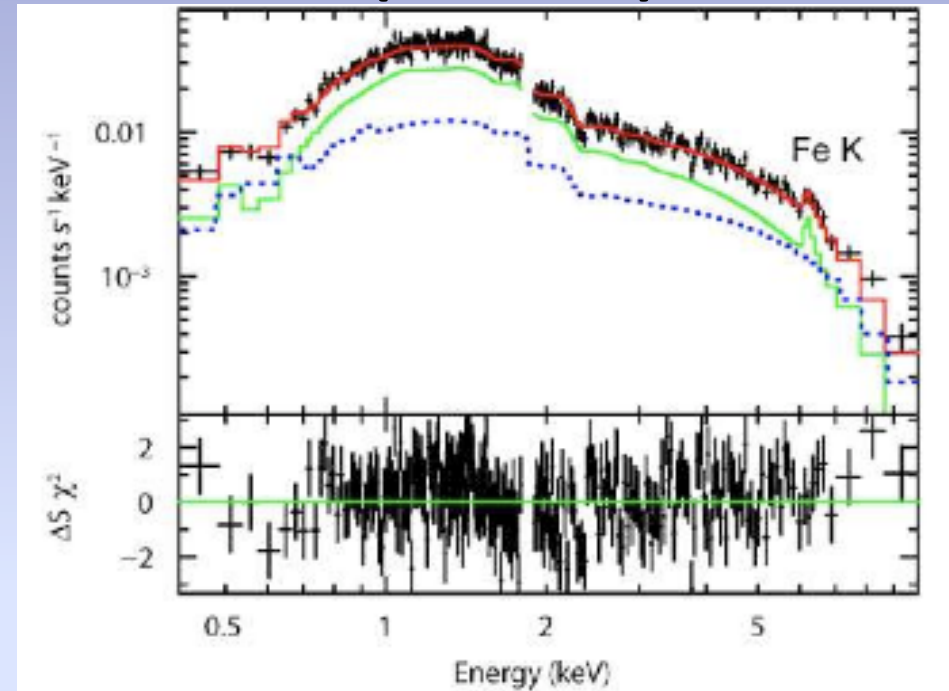
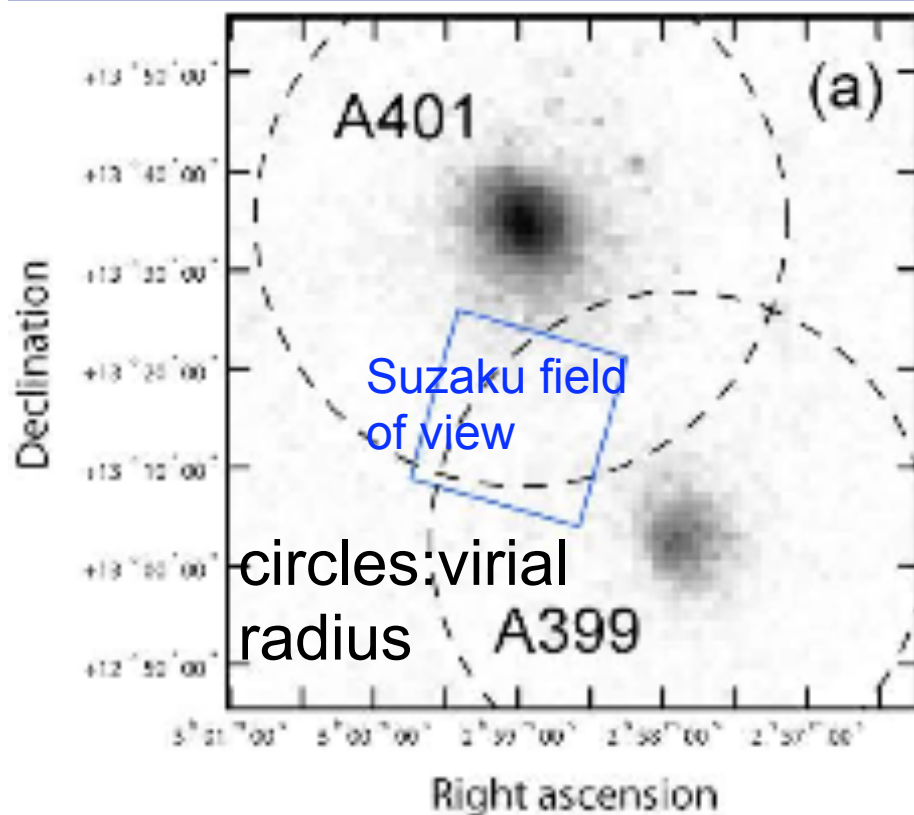
The observed flatter radial profile of the Fe abundance at $0.1-0.5r_{180}$ indicates early metal enrichment than numerical simulation, considering the Fe in the ICM extends further than stars

solar abundance:
loddars (2003)



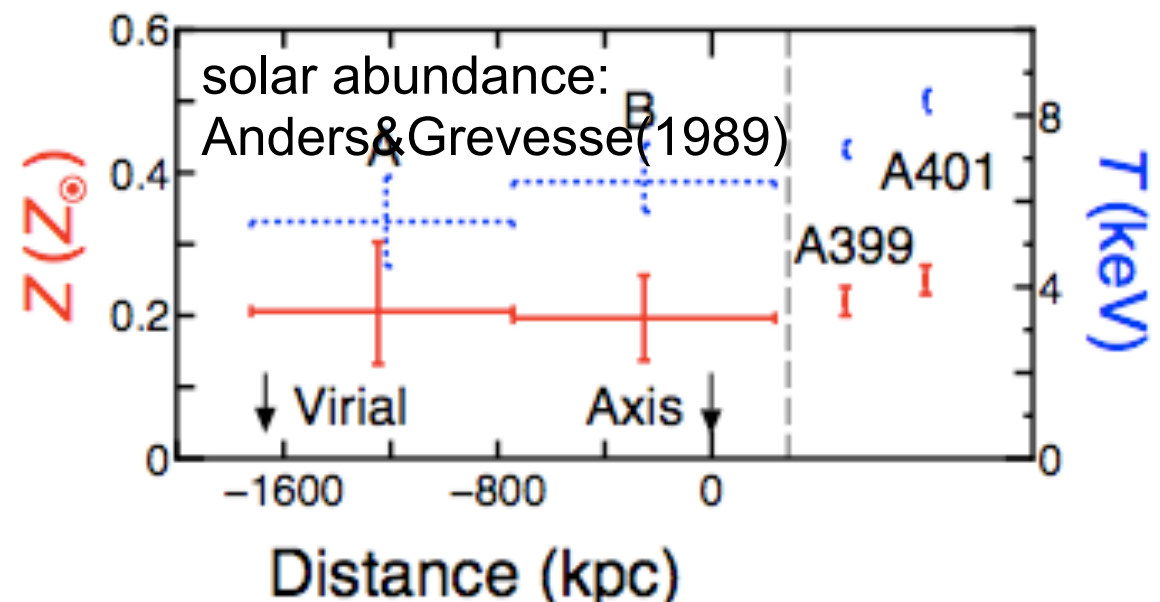
error 68%

Suzaku detection of Fe line up to the virial radius Fujita et al. (2008)



High Fe abundance
@ $0.5-1.0 r_{180}$

Early metal
enrichment

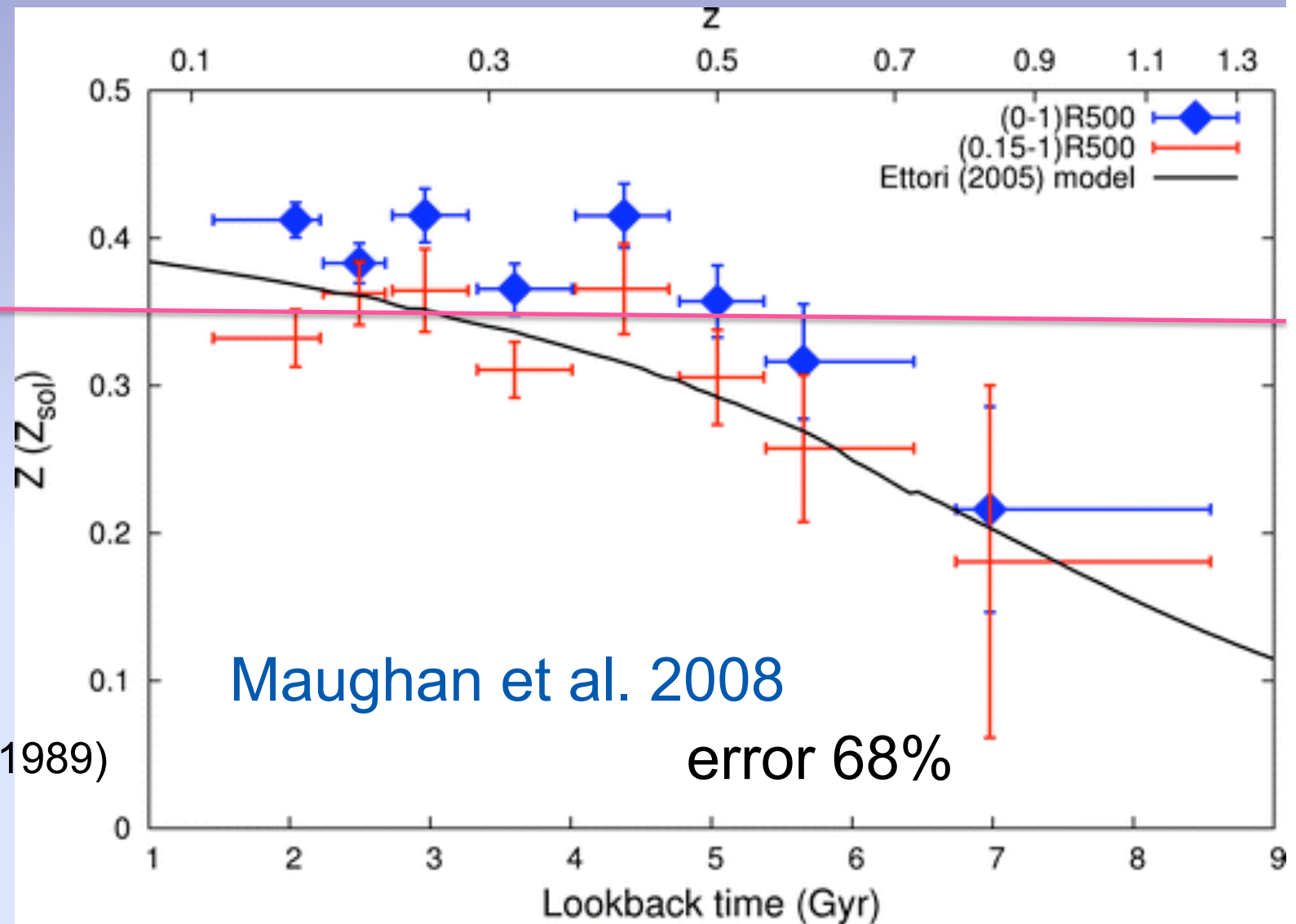


Evolution of Fe abundance of ICM

$z < 0.08$
Matsushita

cooling core
others

solar abundance:
Anders & Grevesse (1989)



consistent with no evolution at least up to $z=0.6$
excluding the central region

Origin of metals in ICM

Abundance pattern of ICM within $0.1r_{180}$ is close to the new solar abundance by Loddars (2003)

- 70-80 % of Fe are synthesized by SN Ia (Sato+07)

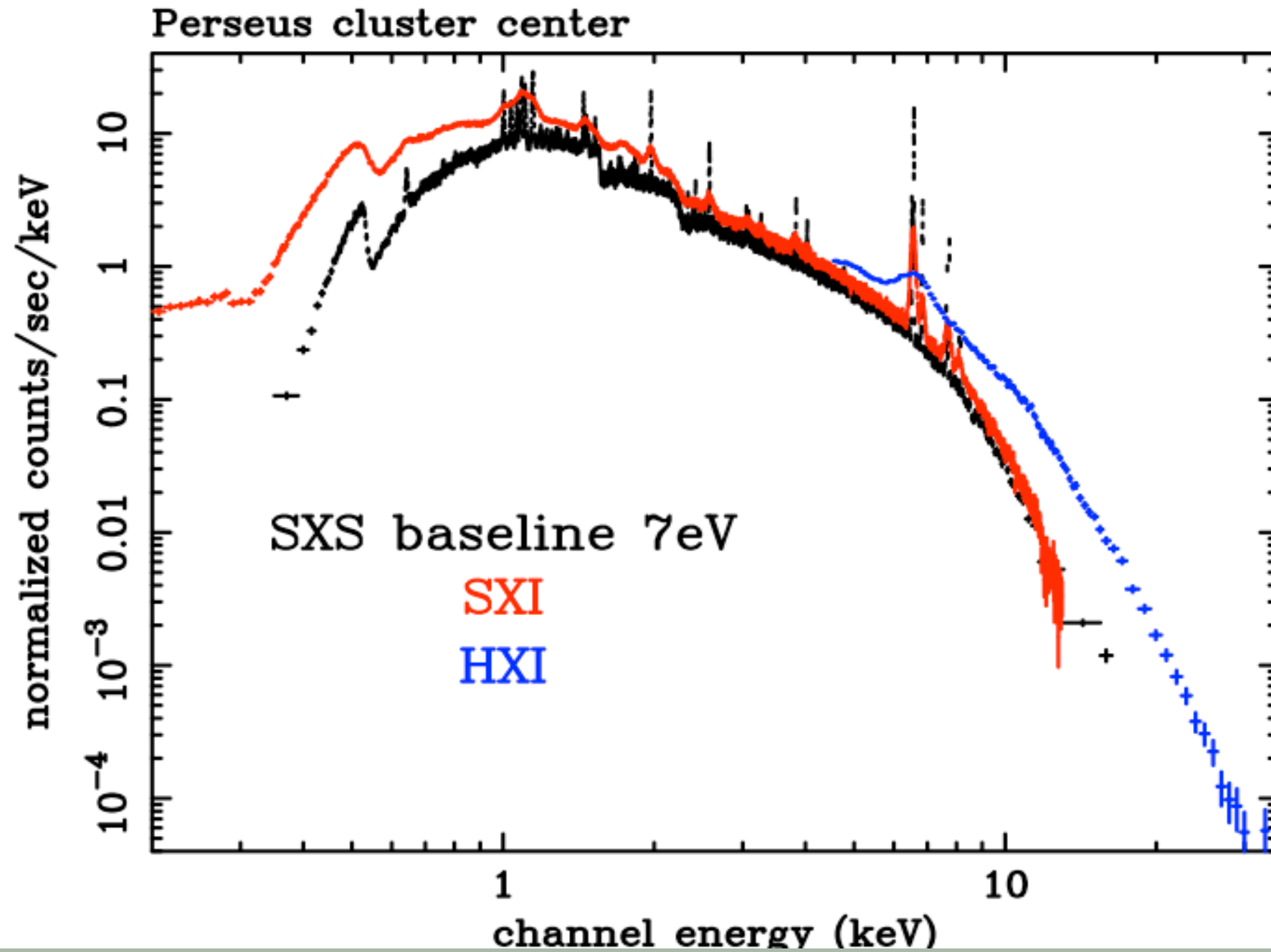
SN II products tend to be more extended than SN Ia products

Extended distribution of Fe than stars and flatter Fe abundance profile at $0.1-0.5r_{180}$

no evolution until $z=0.6$ excluding the central region

- Metal synthesis in early phase in cluster formation

Simulated spectra from the Perseus cluster with Astro-H



Rare metals in hot gas in clusters and galaxies with Astro-H

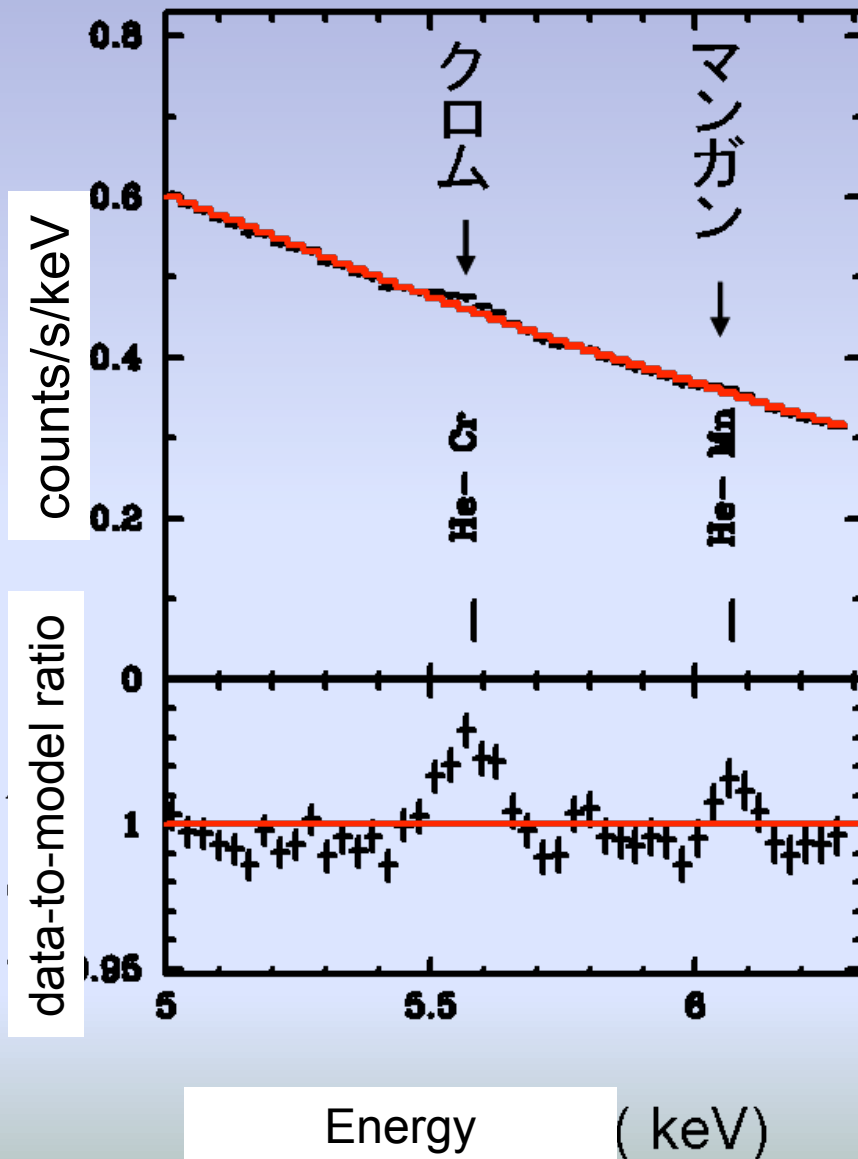
- **Mn/Fe ratio vs. initial mass function of stars**
 - O, Mg are synthesized by SN II.
 - Fe is synthesized by both SN Ia and SN II
 - O/Fe, Mg/Fe ratios from SN II depend on initial mass function of stars
 - SN II do not produce Mn very much
- **Al/Mg ratio vs. progenitor metallicity of SN II.**
 - Al and Mg are synthesized by SN II
 - Al/Mg ratio increases with progenitor metallicity
- **C, N abundances and history of intermediate mass stars**

Cr detection from the Perseus cluster with Suzaku

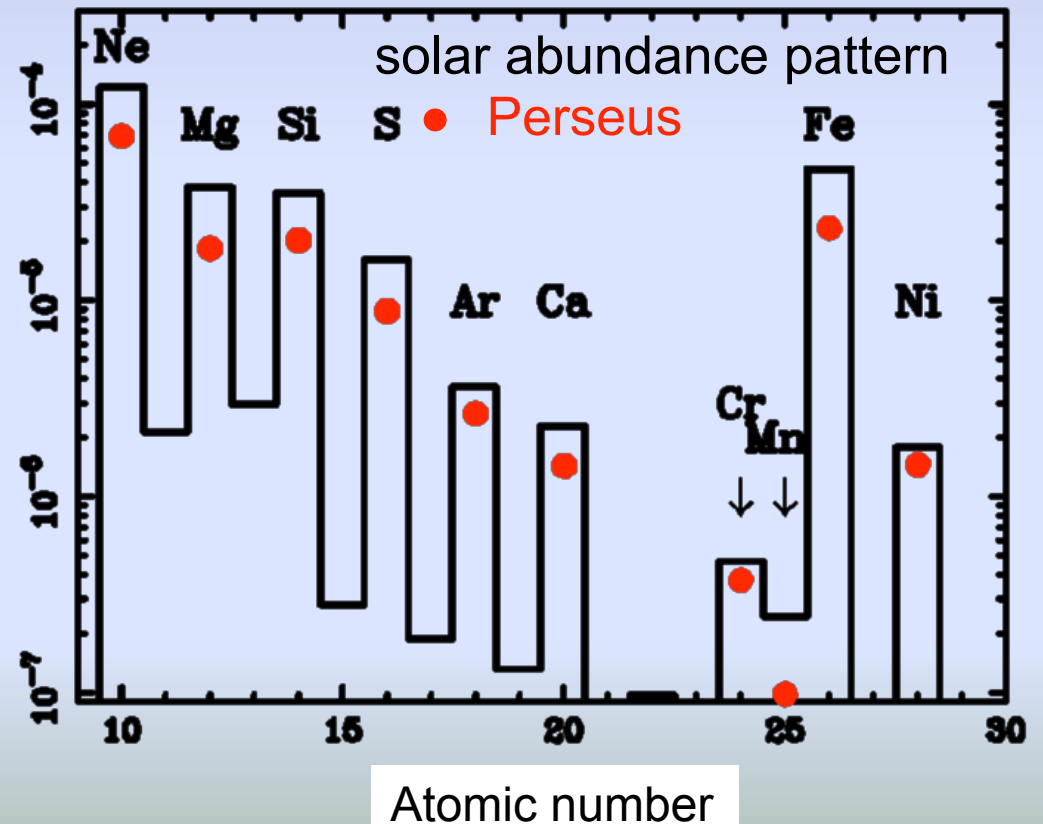
Tamura et al. 2009

also XMM detectinon from **2A 0335+096**
by Werner et al. (2006)

Mn is an indicator of SN Ia, since SN II do not produce Mn very much

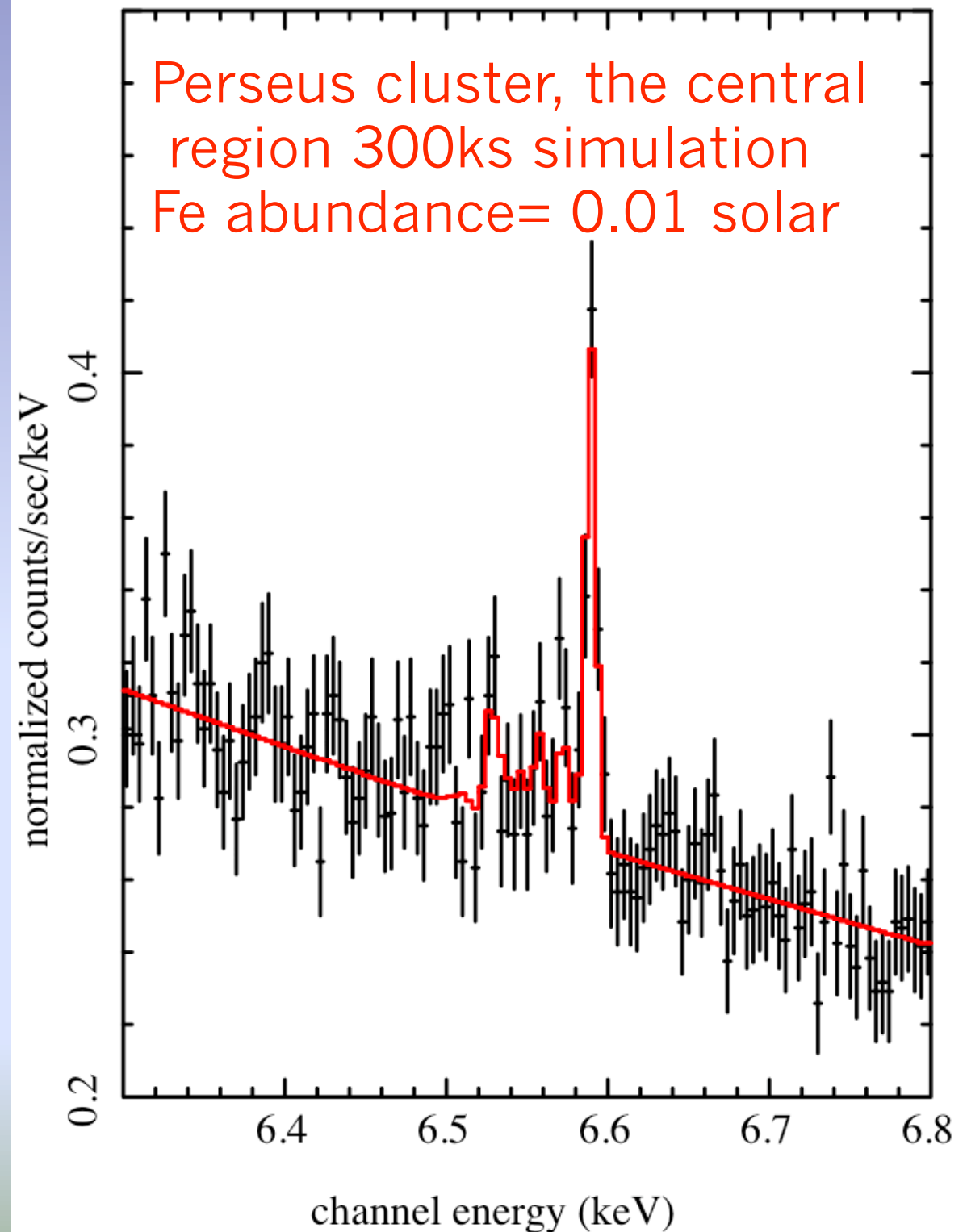


number ratio to H



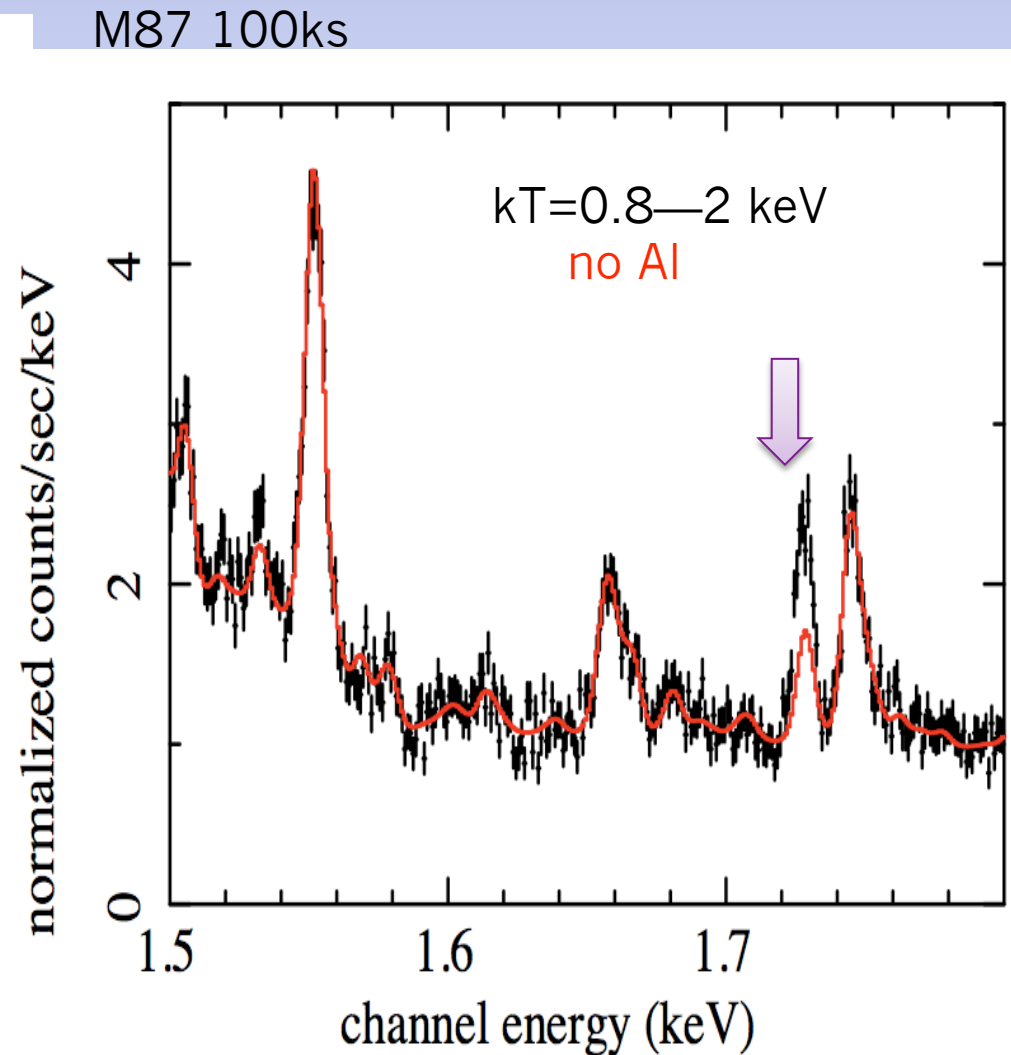
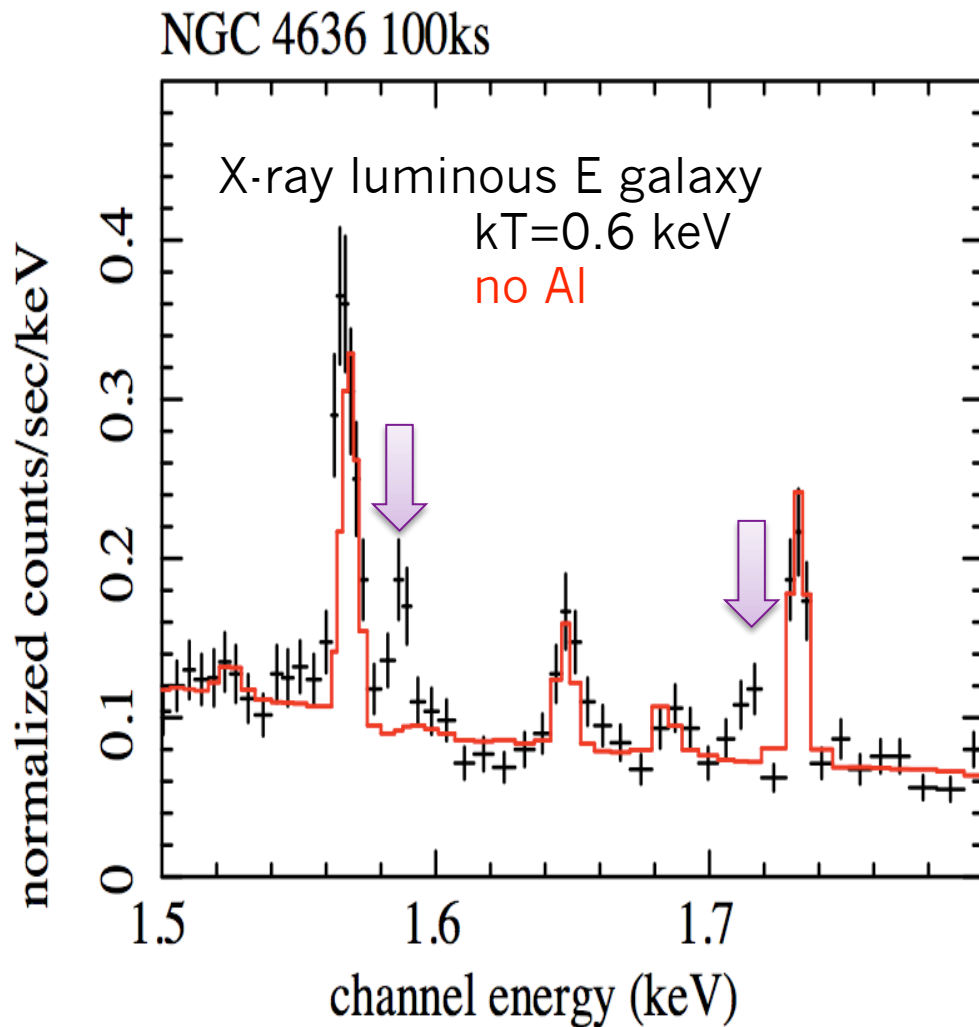
Can Astro-H detect Mn lines?

- With the solar abundance, the Mn/Fe ratio is 0.01 by number ratio.
- Since Mn lines are not included in models, we simulated Fe K lines assuming that Fe abundance=0.01 solar



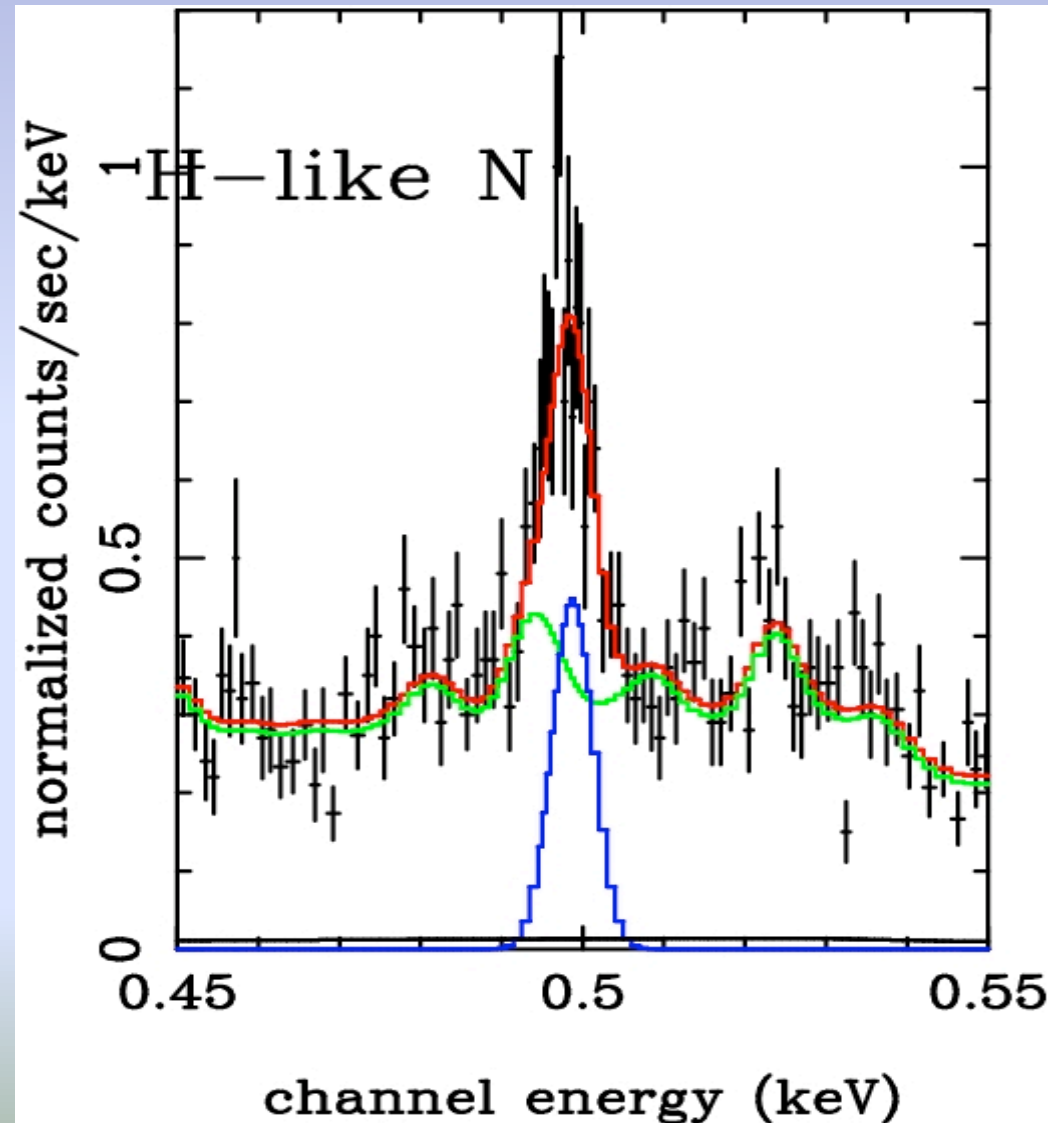
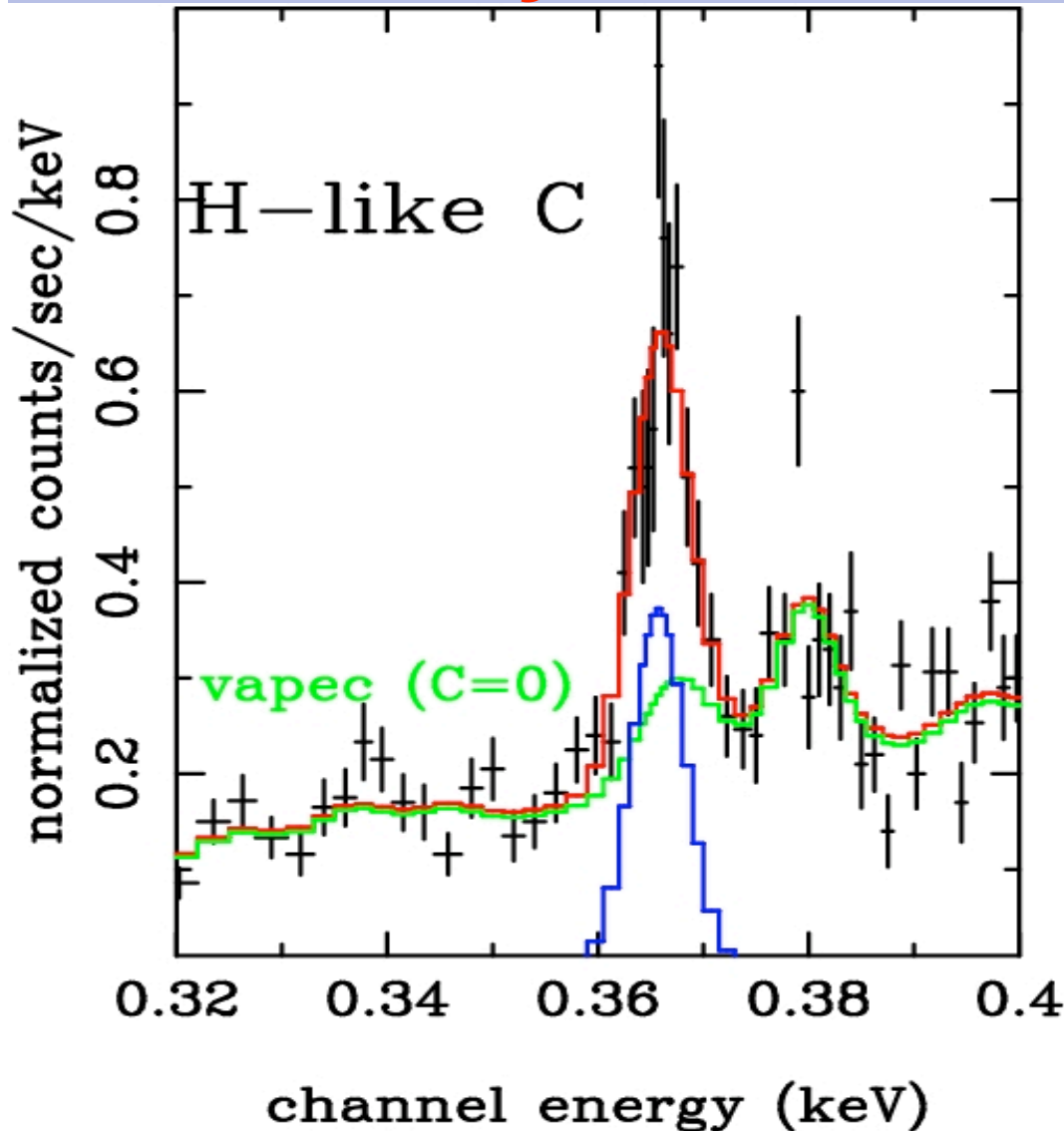
Can Astro-H detect Al lines?

- Al and Mg are synthesized by SN II
- Al/Mg ratio increases with progenitor metallicity



C, N of hot ISM in an X-ray luminous elliptical galaxy, NGC 4636($r < 2'$)

history of intermediate mass stars



rare metals in hot gas in clusters and galaxies with Astro-H

- **Mn/Fe ratio vs. initial mass function of stars**
 - O, Mg are synthesized by SN II.
 - Fe is synthesized by both SN Ia and SN II
 - O/Fe, Mg/Fe ratios from SN II depend on initial mass function of stars
 - SN II do not produce Mn very much
- **Al/Mg ratio vs. progenitor metallicity of SN II.**
 - Al and Mg are synthesized by SN II
 - Al/Mg ratio increases with progenitor metallicity
- **C, N abundances and history of intermediate mass stars**

Summary

Abundance pattern from O to Fe of the ICM within $0.1r_{180}$ is close to that of the new solar abundance by Lodders (2003)

- 80% of Fe come from SN Ia

Early formation of metals in Intracluster Medium (ICM)


- Fe is more extended than stars
- SN II products are more extended than SN Ia products?

Future missions

- rare metals with Astro-H
- metals in clusters up to the virial radius with Xenia

Evolution of SN Ia rate

Accumulating over present SN Ia rate over the Hubble time give observed Fe mass-to-light ratio in clusters?



How to constrain present SN Ia rate in cluster galaxies?



Fe abundances of ISM in early-type galaxies give upper limit in present SN Ia rate